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Spatial Recognition Performance of RFID Tags Integrated With Interior Decorating Panels

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Abstract: Radio Frequency Identification (RFID) technology has not only application in the construction production stage but also has high potential in the operation and maintenance stage after construction is complete. However, it is necessary to understand the operational features and limitations of RFID technology within interior spaces. Through experiments, this study proposes to determine the best method and location to install RFID tags within interior design projects and establish the limitations and best applications of RFID technology for the inspection of interior decorating materials. The results show that when the RFID reader is oriented horizontally and moves toward the wall surface to which the tag is affixed, the recognition accuracy ratio of tags located on the two lateral sides and the underside (parallel to the antenna) of the reader is very low.

Key words: RFID, building material, construction management, interior design

INTRODUCTION

In recent years, Radio Frequency Identification (RFID) technology has been recognized as an important influence on the development of industries globally as well as being useful in many fields. The RFID, initially proposed by Stockman (1948) is a system by which the identification data of objects is stored on IC chips. These IC chips are placed on or embedded in objects that transmit data into the system via., wireless communication (McCarthy *et al.*, 2003). Not, until the 1990s did RFID experience its first large-scale commercial use which was in electronic toll collection on US highways. Since, that time, RFID has been used across multiple industries and has continued to advance in functionality and capability the association for automation identification and data capture technologies (AIM, 2001).

The RFID applications have been marketed for several types of commercial use and implemented for Electronic Toll Collection (ETC), the Easy Card of the Taipei Rapid Transit System, the Octopus Card in Hong Kong as well as for animal identity chips, company security cards and library book management. In the retail market, Wal-Mart has requested its suppliers to utilize RFID for product dispatch. Thus, the use of RFID has potential for future developments. The frequencies commonly used in RFID systems and the applications of each bandwidth are introduced in (Domdouzis *et al.*, 2007; Ward and van Kranenburg, 2006; Landt, 2005).

Most research focuses on communication quality, transmission protocol, data security and privacy among RFID systems (Chien and Laih, 2009; Roh *et al.*, 2009; Xiaohua and Hanbin, 2011; Huang and Chang, 2011). Some of the research investigates logistics (Tajima, 2007), tracking management (Kim *et al.*, 2008; Papapostolou and Chaouchi, 2011), medicine, manufacturing (Ferrer *et al.*, 2011) and agriculture (Ruiz-Garcia and Lunadei, 2011). Application of RFID in the construction industry commenced after 2000 and is used to monitor construction quality and progress management (Domdouzis *et al.*, 2007; Goodrum *et al.*, 2006; Wang, 2008; Umetani *et al.*, 2006), construction safety management (Chae and Yoshida, 2010) and material and supply management (Yagi *et al.*, 2005; Song *et al.*, 2006). In the construction industry, each stage of construction management should provide support and feedback to the others to help reduce the effort of inspection and the amount of paperwork, thereby effectively improving the project's overall efficiency. Automatic recognition through RFID, offers the simple integration of information to a common platform by which complex information can be communicated and conveyed in a short time. It can also improve information between divisions in construction project supply chains resulting in greater uniformity (Lu *et al.*, 2011).

Recent technological advancement in data acquisition systems has made the consistent management of construction components and their information more

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feasible. Several applications using an RFID device attached to construction components have been proposed, these applications include the managing the construction components delivered to a construction site (Chen *et al*., 2002; Ko, 2010; Razavi and Haas, 2011), pose estimation of a component (Tzeng *et al*., 2008) and providing a guide of the construction site (Umetani *et al*., 2006).

Regarding the transportation of construction materials (Song *et al*., 2006) proposed the application of RFID for the transmission and receipt of industrial wires. Using a GPS system, passive RFID tags, a PDA reader (915 MHz, 20-300 ft) and a fixed reader (433.92 MHz, 150 ft) the use of these two different readers permitted data regarding industrial wire transmission and receipt to be precisely read, thereby improving construction efficiency.

Considering the characteristics and limitations of RFID, the RFID technology not only offers advantages in construction management during the production stage but also is valuable in the post construction operation and maintenance stages. However, it is important to understand the operational features and limitations of RFID technology in interior spaces.

Interior design and decorating components can be divided into three major categories; ceiling, wall and floor finishes. According to previous studies, wood is the most frequently used material in all three categories and accounts for more than 62% of the total materials required. According to the Taiwanese building code, new buildings must use a minimum of 30% of interior decorating materials that have acquired a Green Building material certification. Therefore, the on-site inspection of certified Green Building materials will be an important task for the authorities. In this study, we assume that most of the interior decorating building materials used are wood (or other non-metal materials) and the material is tracked or inspected using RFID technology once construction is complete. Our goal for these experiments is to discover the best method and location for placing RFID tags and to determine the limitations and optimal applications of RFID technology in inspecting interior decorating projects.

METHODOLOGY

This study primarily intends to clarify whether passive RFID tags will reflect high recognition rates within the designed application situation (as its product description suggests) and discusses the following topics:

- The recognition accuracy ratio of different measurement angles (formed by a single passive RFID tag and the reader) with various distances and several interior decorating materials
- The recognition accuracy ratio of different measurement angles when the RFID tag is clipped between two pieces of interior decorating materials
- Affixing many RFID tags on different walls to investigate the recognition ratio

Finally, this study comprehensively analyzes the best method for placing passive RFID tags to overcome the limitations of RFID detection. The goal is to reduce errors due to recognition malfunction by adjusting the recognition position and/or changing the method of tag positioning.

Most interior decorating materials are perpendicular to or parallel with the ceiling (or floor) or any one of the walls. Therefore, the experimental design in this study attempts to divide the space into three planes based on three axes: X-Y, X-Z and Y-Z. In addition, according to previous findings (Tzeng *et al*., 2008), when experimenting with a passive RFID system or handheld reader, the best recognition area is the fan-shaped area with angle 30-150°C and radius 150 cm and the penetration of the RF signal from RFID passive tags is weak. Therefore, the recognition distance between tag and reader is 50-250 cm in various experimental stages in this study.

In the selection of experimental equipment, we continue to use an industrial handheld RFID (MC9000G, as shown in Fig. 1) and 13 common passive RFID tags (Table 1) tags 1-6 are conventional sticker-type RFID tags less than 1 mm thick. Tags 7-13 are special 3 to 7 mm thick tag types that include a plastic shell layer outside the tag.

Recognition and error ratios are the main concerns for RFID system planning and use. The recognition of tags was determined by many factors such as the effect of RF transmission power on readable distance, reading failures due to interference from the metal, environmental noise and other factors. The experiments were controlled in a fixed environment and each stage was conducted under identical conditions. The resulting recognition ratios recorded from each experiment at each stage are discussed. The accurate recognition ratio ρ_{OK} is defined as follows:

$$\rho_{OK} = \frac{\text{No. of accurate tag recognitions}}{\text{No. of tag readings}} \quad (1)$$

Experimental stage 1: This stage examined the cognition rates when RFID tags are affixed to the specimen (1 non-metal material and 1 metal material) at different positions under the simplest conditions. The passive tags we chose were affixed to six sides of the specimen (A-F) and tested

Table 1: The RFID tags used in this study

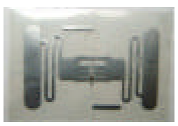
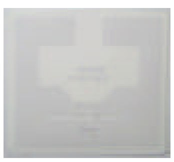
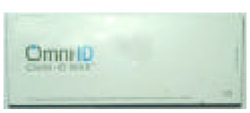
Photo	Specification
	Frequency: 860 and 960 MHz Standard: UHF Class 1, Gen2 Size: 97 mm (L)×13 mm (W)
	Frequency: 860-960 MHz Standard: UHF Class 1, Gen2 Size: 91 mm (L)×31 mm (W)
	Frequency: 902-928 MHz Standard: UHF Class 1, Gen2 Size: 99 mm (L)×11 mm (W)
	Frequency:860-960 MHz Standard:UHF Class 1, Gen2 Size:54 mm (L)×34 mm (W)
	Frequency: 860-960 MHz Standard: EPC Class 1, Gen2 Size: 47 mm (L)×42 mm (W)
	Frequency: 860-960 MHz Standard: Gen2 PVC Card Size: 86 mm (L)×54 mm (W)×1 mm (T)
	Frequency: 860-960 MHz Standard: Gen2 metal Tag Size:150 mm (L)×45 mm (W)×6 mm (T)
	Frequency: 860~960 MHz Standard: Gen2 metal Tag Size: 120 mm (L)×25 mm (W)×6 mm (T)
	Frequency: 902-928 MHz Standard: EPC Class 1, Gen2 Size: 80 mm (L)×30 mm (W)×3 mm (T)
	Frequency: 860-960 MHz Standard: EPC Class 1, Gen2 Size: 105 mm (L)×36 mm (W)×6 mm (T)
	Frequency: 860-960 MHz Standard: EPC Class 1, Gen2 Size: 102 mm (L)×21 mm (W)×6 mm (T)
	Frequency: 860-960 MHz Standard: EPC Class 1, Gen2 Size: 55 mm (L)×16 mm (W)×7 mm (T)
	Frequency: 860-960 MHz Standard: EPC Class 1, Gen2 Size: 33 mm (L)×10 mm (W)×4 mm (T)

Fig. 1(a-b): Radio frequency identification reader (MC9000G) used in this study

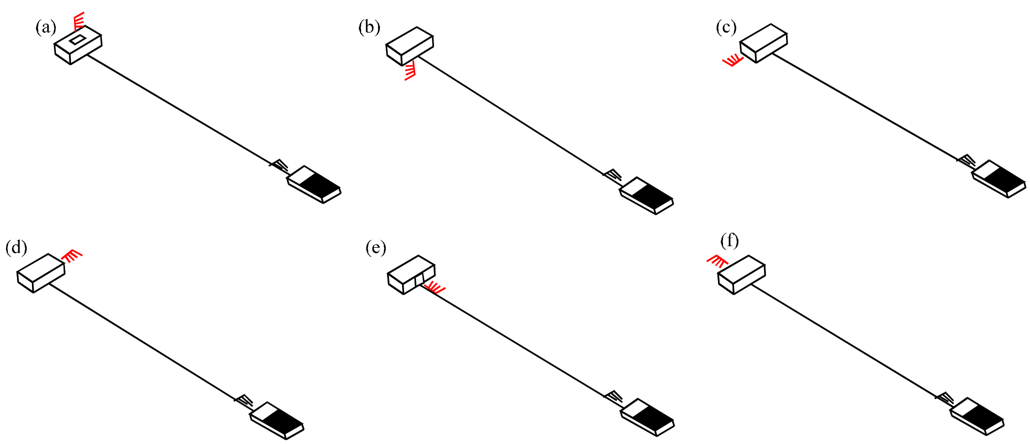


Fig. 2(a-f): Radio frequency identification (RFID) tags affixed to (a) Side A at top, (b) Side B at bottom, (c) Side C at left, (d) Side D at right, (e) Side B front and (f) Side B at back side of the different specimen

according to the abovementioned recognition range (50-250 cm) as shown in Fig. 2 and 3. The specimens are wood and aluminum metal boxes (23×14×7.5 cm).

Experimental stage 2: In this stage, the RFID tag is clipped between two pieces of wooden material (Fig. 4a) to conduct experimental measurements and determine whether the accurate recognition rate of the tag is affected by this clipping. The study divides the space into three planes based on three axes, X-Y, X-Z and Y-Z, Fig. 4b-d and experiments were performed in which the relative positions and distances between the RFID tag and the reader were varied (150, 200 and 250 cm).

Experimental stage 3: In this stage, the walls are divided into many 60×60 cm squares to mimic the division of common interior decorating material as shown in Fig. 5. The X-Y plane represents the floor and the X-Z and Y-Z planes represent the walls. Each plane is divided into 4×4 = 16 square areas and RFID tags are affixed to the

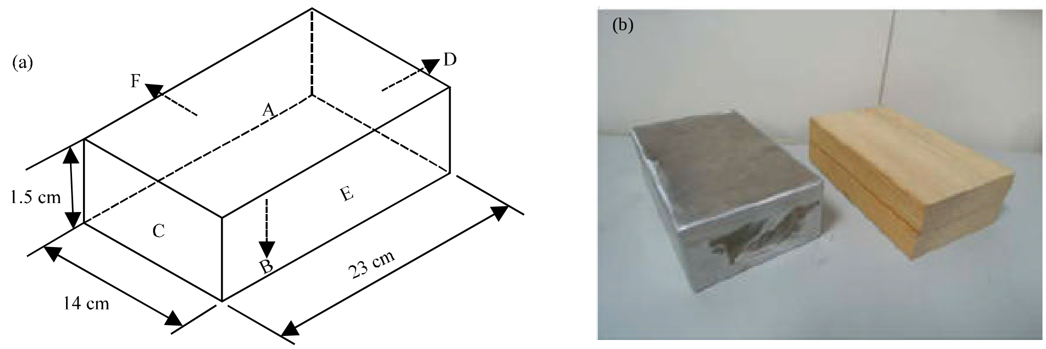


Fig. 3(a-b): Material specimens

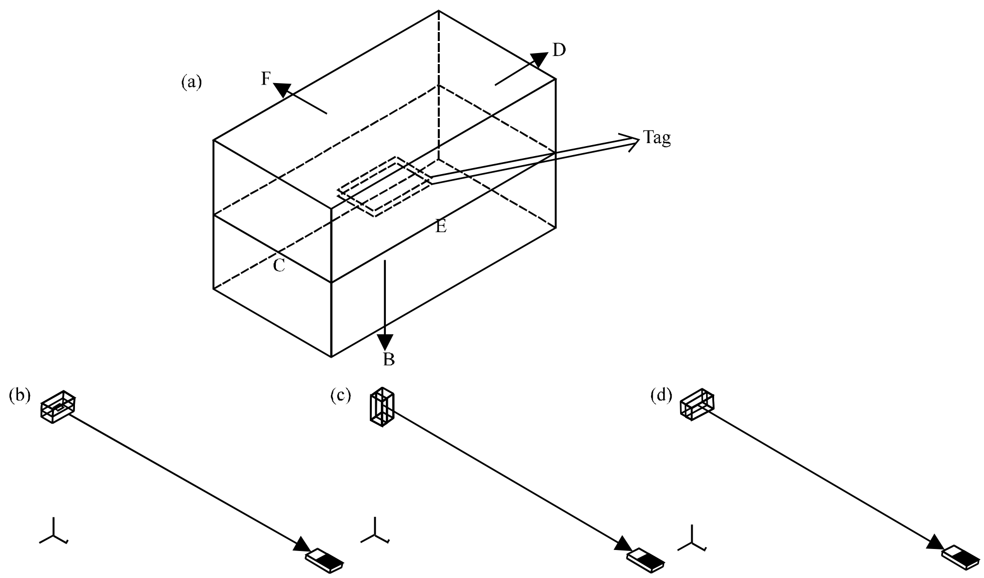


Fig. 4(a-d): A schematic diagram of experimental stage 2 (a) The RFID tag is clipped between specimens, (b) X-Y, (c) Y-Z and (d) X-Z plane measurement

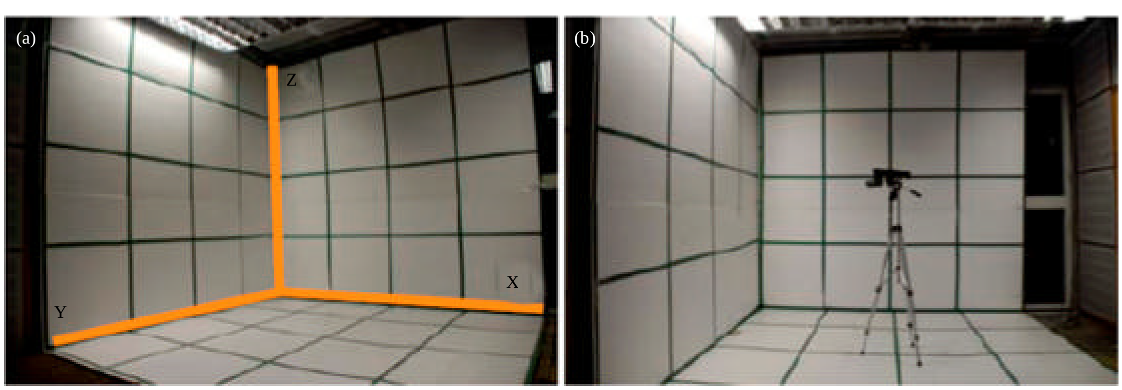
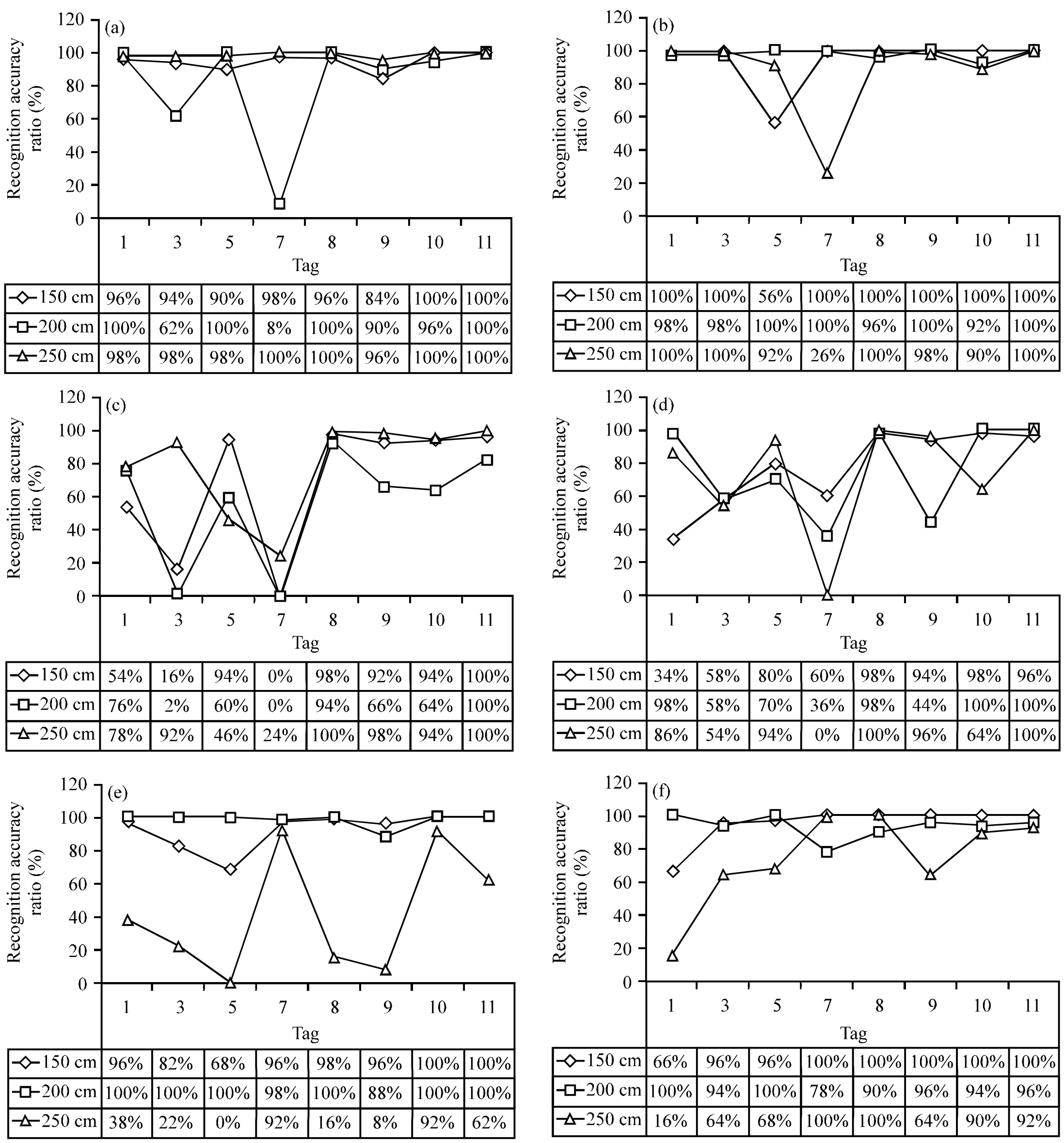


Fig. 5(a-b): Experimental space used in stage 3 center of the squares. We use 48 tags in the experiment. The experiment mainly strives to understand whether the recognition accuracy ratio of RFID tags is affected by varying the distance and the angle of the tags from the reader and whether the recognition accuracy ratio of the RFID is affected by signal interference or signal overlap.

RESULTS AND DISCUSSION

The stage 1 experiments indicate that the reader's reading ability is stable and reliable when the distance between the tag and reader is 50 or 100 cm. Therefore, the study focuses on longer distances (150, 200 and 250 cm) and 50 reading tests are examined for each distance (Table 2 for the results).

Tags 1, 3, 5, 7, 8, 9, 10 and 11 exhibit more accurate recognition ratios (Table 2). Further analysis of the experimental results of these 8 tags and the recognition accuracy ratios of each side (A-F) are shown in Fig. 6. Thus, regardless of distance, when the RFID tags are affixed on side C or side D, the recognition accuracy ratios are very inconsistent. If the RFID



(a)

	1	3	5	7	8	9	10	11
150 cm	96%	94%	90%	98%	96%	84%	100%	100%
200 cm	100%	62%	100%	8%	100%	90%	96%	100%
250 cm	98%	98%	98%	100%	100%	96%	100%	100%

(b)

	1	3	5	7	8	9	10	11
150 cm	100%	100%	56%	100%	100%	100%	100%	100%
200 cm	98%	98%	100%	100%	96%	100%	92%	100%
250 cm	100%	100%	92%	26%	100%	98%	90%	100%

(c)

	1	3	5	7	8	9	10	11
150 cm	54%	16%	94%	0%	98%	92%	94%	100%
200 cm	76%	2%	60%	0%	94%	66%	64%	100%
250 cm	78%	92%	46%	24%	100%	98%	94%	100%

(d)

	1	3	5	7	8	9	10	11
150 cm	34%	58%	80%	60%	98%	94%	98%	96%
200 cm	98%	58%	70%	36%	98%	44%	100%	100%
250 cm	86%	54%	94%	0%	100%	96%	64%	100%

(e)

	1	3	5	7	8	9	10	11
150 cm	96%	82%	68%	96%	98%	96%	100%	100%
200 cm	100%	100%	100%	98%	100%	88%	100%	100%
250 cm	38%	22%	0%	92%	16%	8%	92%	62%

(f)

	1	3	5	7	8	9	10	11
150 cm	66%	96%	96%	100%	100%	100%	100%	100%
200 cm	100%	94%	100%	78%	90%	96%	94%	96%
250 cm	16%	64%	68%	100%	100%	64%	90%	92%

Fig. 6(a-f): Stage 1 results for the non-metal specimens (tags 1, 3, 5 and 7-11) (a) Face A, (b) Face B, (c) Face C, (d) Face D, (e) Face E and (f) Face F

Table 2: Non-metal specimens (stage 1)

Tag (cm)	Face A (%)	Face B (%)	Face C (%)	Face D (%)	Face E (%)	Face F (%)	Average(%)
1							
150	96	100	54	34	96	66	74
200	100	98	76	98	100	100	95
250	98	100	78	86	38	16	69
2							
150	76	82	12	0	58	82	52
200	48	96	0	0	46	70	43
250	92	90	18	0	0	0	33
3							
150	94	100	16	58	82	96	74
200	62	98	2	58	100	94	69
250	98	100	92	54	22	64	72
4							
150	96	90	40	46	36	100	68
200	80	98	36	62	84	24	64
250	100	94	44	22	0	46	51
5							
150	90	56	94	80	68	98	81
200	100	100	60	70	100	100	88
250	98	92	46	94	0	68	66
6							
150	40	60	0	0	22	48	28
200	0	28	0	0	2	0	5
250	0	0	0	0	0	0	0
7							
150	98	100	0	60	96	100	76
200	8	100	0	36	98	78	53
250	100	26	24	0	92	100	57
8							
150	96	100	98	98	98	100	98
200	100	96	94	98	100	90	96
250	100	100	100	100	16	00	83
9							
150	84	100	92	94	96	100	94
200	90	100	66	44	88	96	81
250	96	98	98	96v	8	64	77
10							
150	100	100	94	98	100	100	99
200	96	92	64	100	100	94	91
250	100	90	94	64	92	90	88
11							
150	100	100	96	96	100	100	99
200	100	100	82	100	100	96	96
250	100	100	100	100	62	92	92
12							
150	38	10	2	0	78	20	25
200	6	0	0	0	4	46	9
250	30	6	0	0	0	0	6
13							
150	4	2	0	0	12	2	3
200	8	0	0	0	0	0	1
250	0	0	0	0	0	0	0

tags are affixed on side A, B, E or F, the recognition accuracy ratios are higher within 150-200 cm.

In the experiments on the metal specimens, RFID tags are affixed on six sides of a metal specimen and reading tests for different distances (150, 200 and 250 cm) are performed 50 times per specimen. The results demonstrate that Tags 1 to 6 do not work at all and only tags 7-13 (of thickness>3 mm) can be read partially successfully, as shown in Fig. 7. The results demonstrate that the experimental results are not satisfactory regardless of distance. That is, the recognition accuracy ratio of RFID tags is greatly affected by the fact that they are affixed to a metal specimen, this is especially true of the sticker-type RFID tags (of thickness<1 mm) because their RF signal will be completely absorbed by the metal surface and the RFID system will fail to function.

The previous result demonstrates that Tags 1, 3, 5, 7 and 8 have more accurate recognition ratios. Therefore,

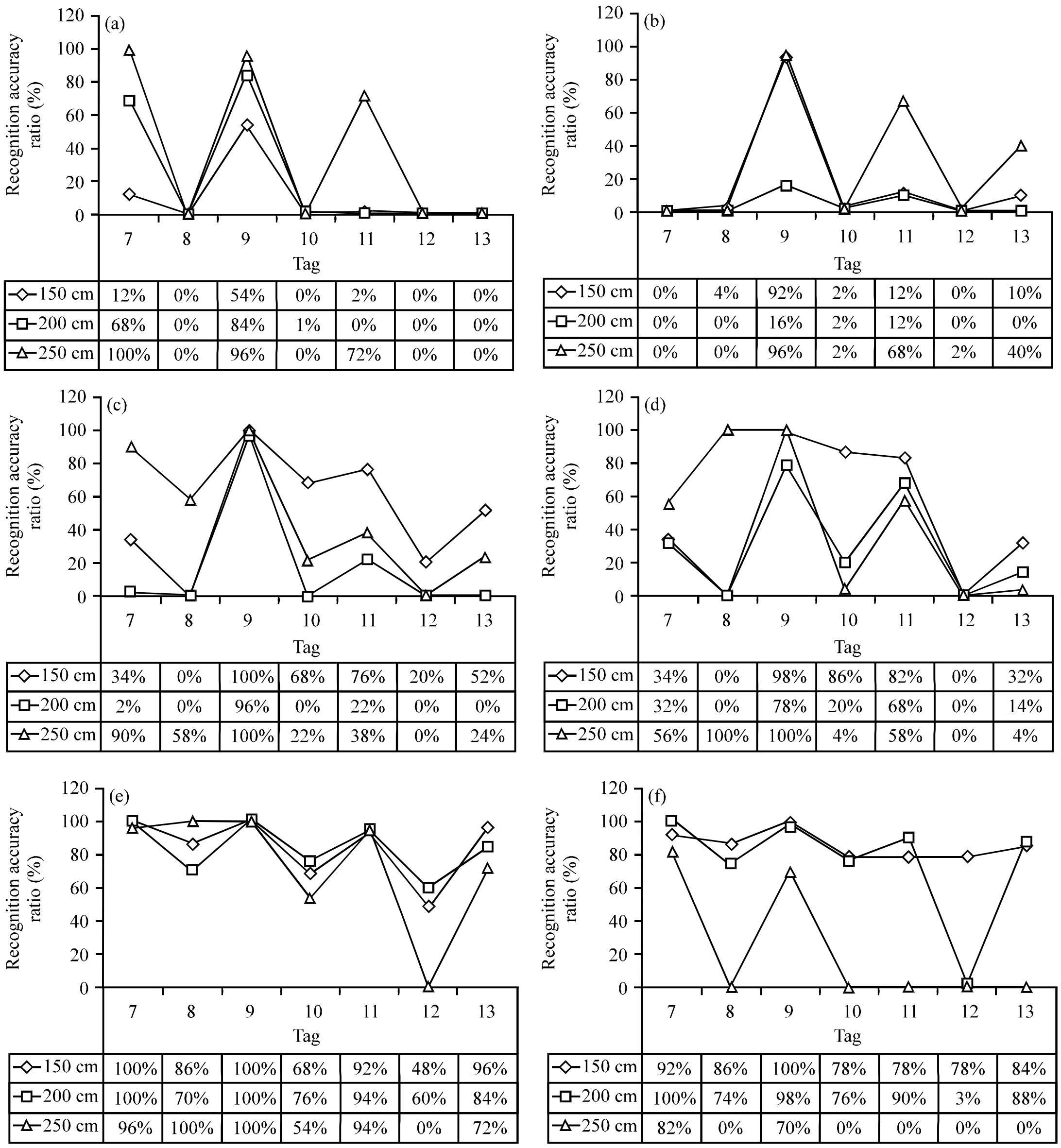
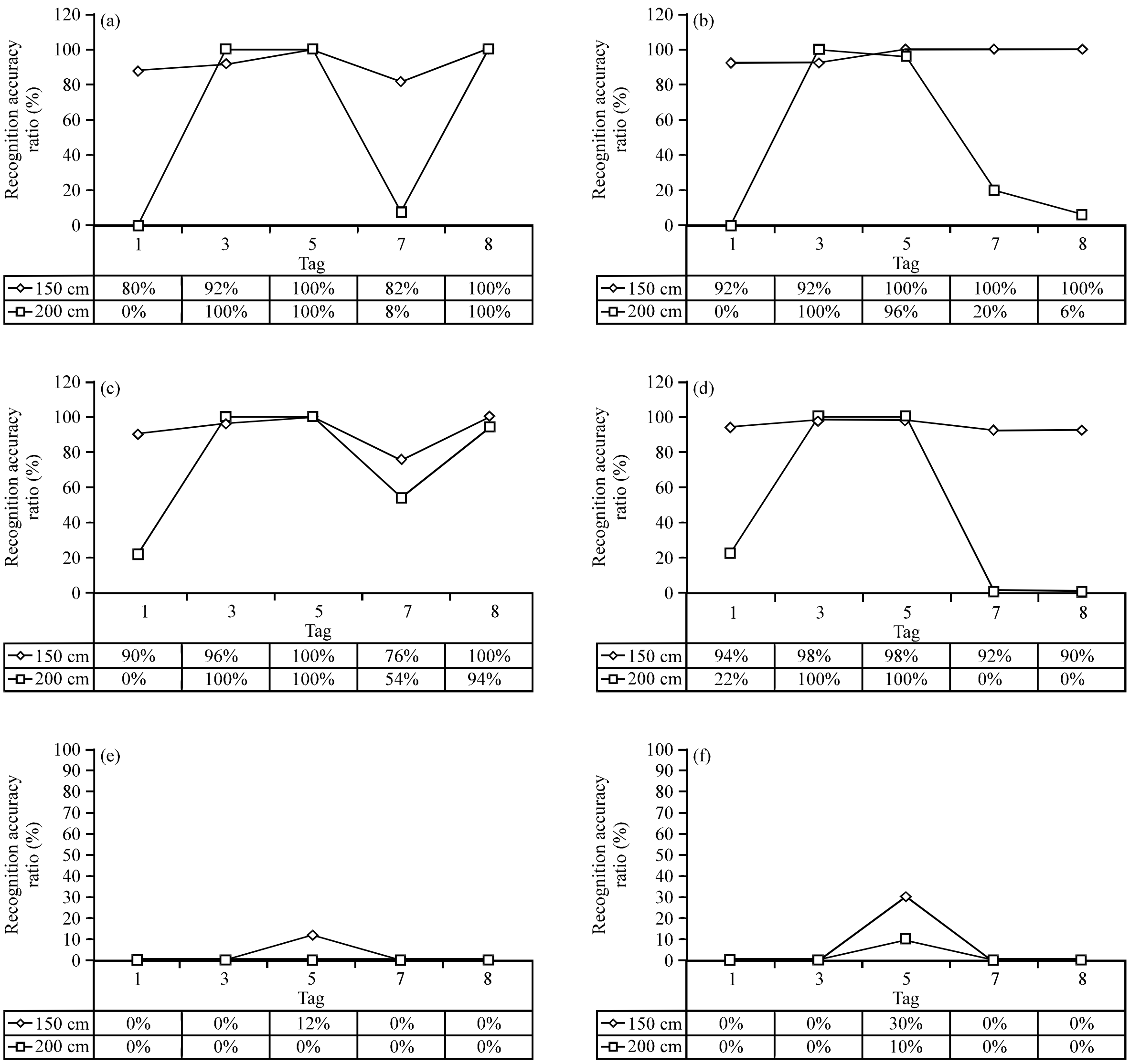


Fig. 7(a-f): Stage 1 results for the metal specimens (tags 7-13) (a) Face A, (b) Face B, (c) Face C, (d) Face D, (e) Face E and (f) Face F

we continue to apply these tags in stage 2. We attempt to clip the same two RFID tags between two specimens and repeat the 50 reading tests for different distances (150 and 200 cm, respectively).

The experimental results from stage 2 (Fig. 8) demonstrate that no regardless of what side the tag is facing, the recognition accuracy ratio is very stable (>80%) when the tag is located on the X-Y or X-Z planes and the distance is 150 cm. However, the recognition accuracy ratio becomes very low when the distance is 200 cm. It can be seen that even if the tag is located in a stable and readable position, the effective reading range will be significantly reduced if the tag and the reader are blocked by goods and the recognition accuracy ratio will be further affected. When the tag is located in the Y-Z plane, the recognition accuracy ratio is very low regardless of what side the tag is facing; even the recognition accuracy ratios of Tags 3 and 5 which perform well in the X-Y and X-Z plane experiments, are significantly reduced when they are clipped in the Y-Z plane. We can infer from the results of this stage that the most important factor influencing the recognition accuracy ratio is the angle between the passive tag and the reader, followed by the distance between them.



(a)

Tag	1	3	5	7	8
150 cm	80%	92%	100%	82%	100%
200 cm	0%	100%	100%	8%	100%

(b)

Tag	1	3	5	7	8
150 cm	92%	92%	100%	100%	100%
200 cm	0%	100%	96%	20%	6%

(c)

Tag	1	3	5	7	8
150 cm	90%	96%	100%	76%	100%
200 cm	0%	100%	100%	54%	94%

(d)

Tag	1	3	5	7	8
150 cm	94%	98%	98%	92%	90%
200 cm	22%	100%	100%	0%	0%

(e)

Tag	1	3	5	7	8
150 cm	0%	0%	12%	0%	0%
200 cm	0%	0%	0%	0%	0%

(f)

Tag	1	3	5	7	8
150 cm	0%	0%	30%	0%	0%
200 cm	0%	0%	10%	0%	0%

Fig. 8(a-f): Stage 2 results (tags 1, 3, 5, 7 and 8) (a) Tag is located on the X-Y plane (facing side A), (b) Tag is located on the X-Y plane (facing side B), (c) Tag is located on the X-Z plane (facing side E), (d) Tag is located on the X-Z plane (facing side F), (e) Tag is located on the Y-Z plane (facing side C) and (f) Tag is located on the Y-Z plane (facing side D)

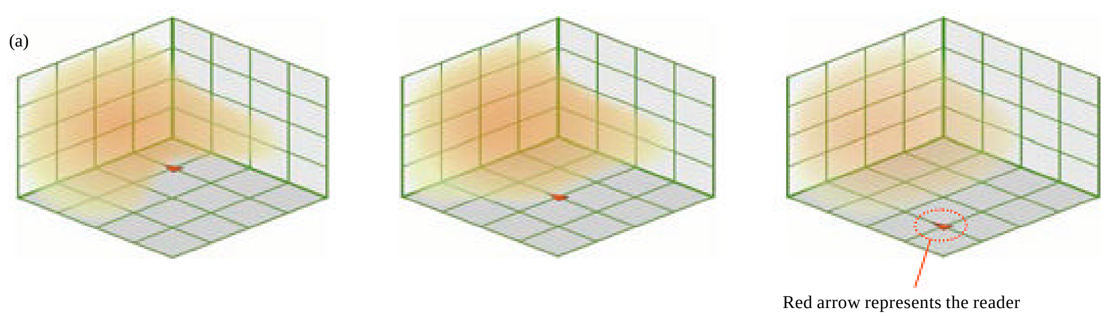


Fig. 9(a-d): Continue

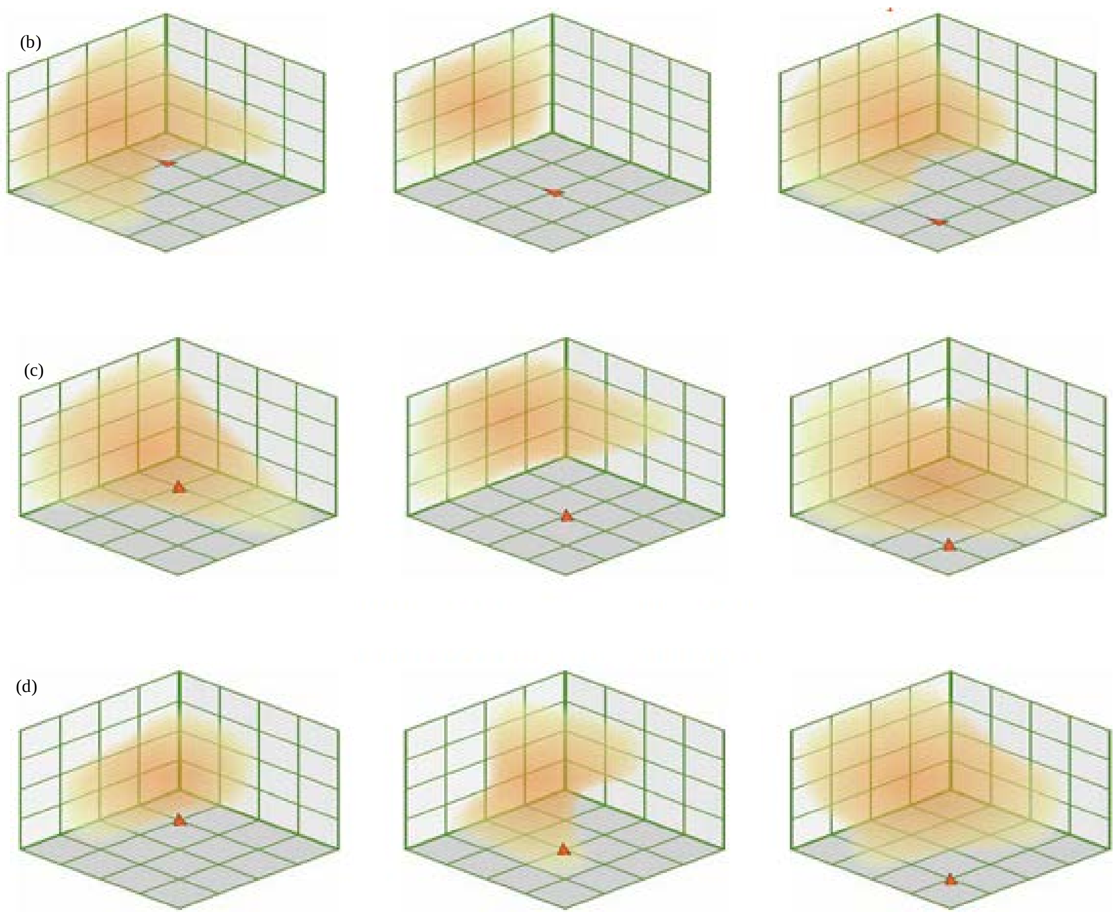


Fig. 9(a-d): Stage 3 results (tags 1 and 5) (a) Reader faces the Y-Z plane (tag 1), (b) Reader faces the Y-Z plane (tag 5), (c) Reader faces the Z-axis (tag 1) and (d) Reader faces the Z-axis (tag 5)

The results from experimental stage 3 are shown in Fig. 9. The recognition accuracy ratios of tags located on the orange gradient area are greater than 70%. If the tag is affixed on the walls which are rear to the reader, it cannot be read. Figure 9a and b demonstrate that when the reader is oriented parallel to the X-axis and faces the Y-Z plane (Fig. 5), the recognition accuracy ratio is lower than when it faces the X-Z plane. This result is consistent with experiment stage 1. Figure 9c and d demonstrate that when the antenna of the reader faces the Z-axis and the angle between the antenna and the X-Z or Y-Z plane is 45°C, the recognition accuracy ratio of the tags on these two wall surfaces is higher because the angle is smaller.

CONCLUSION

In this study, the angle between the passive tag and the reader is the factor that most affects the recognition accuracy ratio followed by the distance between the tag and the reader. When the reader is located horizontally and moves toward the wall surface to which the tag is affixed, the recognition accuracy ratio of tags located on two lateral sides and the underside (parallel to the antenna) is very low. This study reconfirms that metal materials have a great impact on RFID signal transmission especially from sticker-type tags (of thickness <1 mm). The integration with metal materials could even cause the RFID system to fail. The study further defined the characteristics of RFID technology in physical spaces. Although RF has no directivity, the passive RFID signals are weaker and if a tag is affixed to the rear of the reader, the readout could be invalid.

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